

C-1 STATEMENT OF WORK

Research and Technologies for Aerospace Propulsion Systems (RTAPS)

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RESEARCH AND TECHNOLOGIES FOR AEROSPACE PROPULSION SYSTEMS (RTAPS)

STATEMENT OF WORK

1.0 Objective

The objective of this proposed task order contract is to develop, demonstrate, and verify advanced propulsion system technologies as part of NASA's ongoing, long-term aerospace research programs, addressing a wide variety of propulsion issues. Applications include subsonic, supersonic, hypersonic, and rotorcraft transportation vehicles, as well as aviation safety and space exploration applications.

2.0 Scope

The Contractor shall furnish all personnel, facilities, equipment, material, supplies, and services, except as may be expressly set forth in the contract agreement as Government Furnished Property, and otherwise do all things necessary to, or incident to, performing and providing the work efforts set forth in the following areas. Contract scope includes analytical and experimental investigations covering a wide variety of propulsion components and sub-components having either Government, commercial, or military application. . This contract may be used to support all NASA Centers that require work within the scope of this Statement Of Work. The contractor shall perform task orders in the following technology areas:

2.1 RESERVED

2.2 RESERVED

2.3 RESERVED

2.4 Technology Area 4: Space Propulsion

The contractor shall conduct research and development in advanced space propulsion technologies to enable missions with higher performance, reduced cost, improved reliability, and improved safety. Examples of missions currently under consideration and potential technology applications for those missions are listed in Table 2.4.1.

TABLE 2.4.1.—EXAMPLE POTENTIAL APPLICATIONS

Mission	Potential Technology Application
Space Exploration: Lunar lander ascent stage	Liquid oxygen/liquid methane main and RCS propulsion; High-performance hypergolic propulsion
Space Exploration: Lunar lander descent stage	Liquid oxygen/liquid hydrogen throttle-able main propulsion
Space Exploration: Ares V upper stage	Liquid oxygen and liquid hydrogen long-term storage
Science: Titan Explorer	Electric propulsion
Science: Comet sample return	High-performance hypergolic propulsion, electric propulsion
Science: Mars sample return	High-performance chemical propulsion, electric propulsion
Aeronautics: Air breathing access to space	Rocket-based combined cycle propulsion technologies

The contractor shall develop component, subsystem and system technologies for chemical and electric propulsion devices. The scope of these efforts include thrust chamber assemblies (TCAs), turbopump assemblies (TPAs), propellant feed and storage, instrumentation, and electrical elements. In addition, the contractor shall conduct research on non-traditional space propulsion systems such as rocket based combined cycle systems and nuclear thermal propulsion. . The contractor shall address technical challenges in alternate propellants, thruster performance, novel concepts, thermal control, cryogenics, propellant and combustion product properties, chemistry, fluid dynamics, and advanced concept design and fabrication.

2.4.1 Propulsion System Design and Trade Studies

In order to focus technology development efforts, the contractor shall conduct system studies that include analysis, conceptual design, and detailed design of advanced propulsion system components and subsystems. Analysis and design efforts shall address structural, thermal, performance, mass/power estimation, actuation and controls, and integration issues.

The scope of work under this element includes the following:

- (1) The contractor shall define goals and figures of merit for overall systems as well as for individual technologies within the context of overall program and project goals and objectives.
- (2) The contractor shall conduct technology trade studies, evaluating engine concepts and performing conceptual and preliminary design studies to identify and evaluate engine systems and assess their contributions towards meeting program and project goals and objectives.
- (3) The contractor shall conduct risk assessments of advanced propulsion systems.
- (4) The contractor shall define technology development plans to ensure the availability of the key technologies for advanced propulsion systems.
- (5) The contractor shall perform system simulations of propulsion systems and their installations on aerospace vehicles from a 0-D level up through a multidisciplinary 3-D level. The contractor shall also generate propulsion system designs to perform system simulations.
- (6) The contractor shall perform vehicle conceptual design studies, mission analyses, and market and cost scenario studies in support of engine technology impact evaluations.

2.4.2 Nontoxic Chemical Propulsion Systems

The contractor shall develop nontoxic propellant space engine technology for use in lieu of currently operational toxic monopropellant and bipropellant engine technology. The contractor shall focus on the specific technologies listed below for rocket engine and thrust chamber assemblies to meet proposed engine requirements:

- Propellant injectors that provide stable, uniform combustion over a wide range of propellant inlet conditions.
- Combustion chamber thermal control technologies or material technologies which offer improved performance and adequate chamber life.
- Advanced nozzle materials and innovative designs.

- Advanced pre-burners and other pre-conditioning gas generator systems.
- Advanced turbomachinery including fuel and oxidizer pumps and turbines.
- Highly reliable, long-life, fast-acting valves.
- Reliable ignition systems, including subcomponents such as exciters, spark plugs and other ignition sources.
- Non-toxic propellant development and properties assessments.
- Cryogenic instrumentation such as pressure and temperature sensors that will operate for months/years instead of hours.

The scope of work under this element includes the following

(1) The contractor shall conduct an assessment of advanced concepts, analytical tools and barrier technologies for the design of rocket thrust chamber assemblies and nozzles that address the above technologies.

(2) The contractor shall develop and validate empirical, statistical, and physics-based analytical models for predicting engine performance and/or combustion stability.

(3) The contractor shall develop conceptual designs of thrust chamber components, including but not limited to injectors, igniters, valves, combustion chambers, turbomachinery and nozzles.

(4) The contractor shall design and fabricate test hardware for measurement of rocket combustion performance, flow characteristics, and heat transfer.

(5) The contractor shall demonstrate advanced technologies in components, sub-system, or system test rigs. The demonstrations shall include sea level and vacuum test facilities required to assess the performance, life, reliability and operability of rocket engine thrust chamber assemblies.

2.4.3 Hypergolic Propulsion Systems

The contractor shall conduct research and development of advanced hypergolic propellant space engine technology. The contractor shall focus on the specific technologies listed below for rocket engine and thrust chamber assemblies to meet proposed engine requirements

- Propellant injectors that provide stable, uniform combustion over a wide range of propellant inlet conditions.
- Combustion chamber thermal control technologies or material technologies which offer improved performance and adequate chamber life.
- Nozzle materials and innovative designs/manufacturing techniques.
- Advanced turbomachinery including fuel and oxidizer pumps and turbines.
- Highly reliable, long-life, fast-acting and variable-acting valves.

- Propellant/materials compatibility.
- Instrumentation such as Fuel and Oxidizer Reaction Products (FORP) tolerant ignition sensors or highly sensitive flow meters for leak detection.

The scope of work under this element includes the following:

(6) The contractor shall conduct an assessment of advanced concepts, analytical tools and barrier technologies for the design of rocket thrust chamber assemblies and nozzles that address the above technologies.

(7) The contractor shall develop and validate empirical, statistical, and physics-based analytical models for predicting engine performance and/or combustion stability.

(8) The contractor shall develop conceptual designs of thrust chamber components, including but not limited to injectors, igniters, valves, combustion chambers, turbomachinery and nozzles.

(9) The contractor shall design and fabricate test hardware for measurement of rocket combustion performance, flow characteristics, and heat transfer.

(10) The contractor shall demonstrate advanced technologies in components, sub-system, or system test rigs. The demonstrations shall include sea level and vacuum test facilities required to assess the performance, life, reliability and operability of rocket engine thrust chamber assemblies.

2.4.4 Propellant Systems

The contractor shall develop propulsion systems for both human and robotic exploration of the solar system. The propulsion systems will consider the use of both cryogenic and noncryogenic propellants.

2.4.4.1 Cryogenic Propellant Systems

The contractor shall investigate cryogenic and gaseous propellants including liquid or gaseous oxygen (LO₂), liquid or gaseous methane (LCH₄) and/or liquid or gaseous hydrogen (LH₂) for the in space portions of the missions.

For concepts that will require the cryogenic propellant inventory in the vehicles to be maintained, the contractor shall develop technologies to address propellant storage under ground hold, the launch transient, a long-term quiescent in-space period, trans lunar/Mars injection and while in orbit. The contractor shall develop technologies to deliver the cryogenic propellants in a vapor free condition to the Reaction Control Systems (RCS) thrusters and the Main Propulsion Systems (MPS) engines of the vehicle. The contractor shall develop and mature advanced cryogenic storage technologies to reduce the propellant losses due to environmental heating as a result of anticipated on-orbit storage durations of months to years, coupled with the ground hold and launch transient time periods.

The contractor shall have prior experience in the development, design, manufacturing, test, integration, and flight application of cryogenic and gaseous fluid management technologies for space propulsion systems.

The scope of work under this element includes the following:

- (1) The contractor shall design, develop, and validate thermal control system technologies including

but not limited to multi-layer insulation, low conductivity structural systems, cryocoolers, solar shading and radiation shields.

(2) The contractor shall design, develop, and instrumentation including low-gravity gauging, flow, pressure, leak, and temperature measurement.

(3) The contractor shall design, develop, and validate low-gravity propellant management devices including surface tension based liquid acquisition devices and mission operational controls.

(4) The contractor shall design, develop, and validate pressure control systems including mixers, thermodynamic vents, and conventional vents.

(5) The contractor shall design, develop, and validate pressurization systems (autogenous and nonautogenous).

(6) The contractor shall perform computational analysis of CFM components and subsystems.

2.4.4.2 Noncryogenic (Earth-storable) Propellant Systems

The contractor shall investigate propellant system architectures such as monopropellant, bipropellant, and dual-mode systems. The noncryogenic propellants of interest include, but are not limited to, hydrazine (N_2H_4), nitrogen tetroxide (NTO), and monomethylhydrazine (MMH). The contractor shall develop advanced propellant system concepts to enable the propellant inventory in the vehicles to be maintained during ground hold, the launch transient, a long-term quiescent in-space period, trans lunar/Mars injection and while in orbit.. The contractor shall develop advanced propellant storage systems with low mass fraction, such as composite based propellant storage tanks. The contractor shall also develop advanced systems to raise engine inlet manifold pressure, such as pumping systems separate from the engine, to significantly improve the state-of-the-art in propellant delivery systems by decoupling engine inlet pressure from tank storage pressure. The contractor shall also develop advanced thermal control systems to maintain propellant temperatures above their freezing point while consuming a minimum of power for long duration missions.

The scope of work under this element includes the following:

(1) The contractor shall design, develop, and validate thermal control system technologies including but not limited to multi-layer insulation, tank and line heater technology, solar shading and radiation shields.

(2) The contractor shall design, develop, and validate instrumentation including low-gravity gauging, flow, pressure, leak, and temperature measurement.

(3) The contractor shall design, develop, and validate low-gravity propellant management devices including surface-tension-based liquid acquisition devices and mission operational controls.

(4) The contractor shall design, develop, and validate pressurization systems including mechanical and closed-loop pressure control systems, inert gas pressurization system, and self-pressurization concepts.

(5) The contractor shall design, develop, and validate propellant pumping systems to raise engine inlet manifold pressure, including turbine- and piston-based pumps.

(6) The contractor shall design, develop, and validate low mass fraction propellant storage tanks.

(7) The contractor shall perform computational analysis of fluid components and subsystems.

2.4.5 Electric Propulsion

The contractor shall conduct research and development in advanced electric propulsion technologies. Electric propulsion technology is a key technology with the potential to support all four science areas of NASA's Science Mission Directorate-Astrophysics, Earth Science, Heliophysics, and Planetary Science. Electric propulsion is the baseline primary propulsion for a number of mission concepts presently under development for both Planetary Sciences and Astrophysics, and has the potential to support the other two science areas for missions requiring high total impulse.

The scope of work under this element includes the following:

(1) The contractor shall execute detailed propulsion system trade studies to develop system concepts and architectures, and to evaluate and compare electric propulsion options for mission applications of interest.

(2) The contractor shall design, fabricate, and test of thruster components, thrusters, propellant feed systems, power and control systems, and other components and subsystems of electric propulsion systems necessary for the advancement of technical maturity and transition to flight application.

(3) The contractor shall develop and apply analytical tools to evaluate the technical maturity of electric propulsion subsystems and systems, to include cost, risk, reliability, performance, and life.

2.4.6 Rocket-Based Combined Cycle Propulsion Systems

The contractor shall conduct research and development in advanced rocket-based combustion systems technologies. Rocket-based combined cycle (RBCC) propulsion systems offer the potential for improved safety (robustness), increased payload, reduced vehicle size and/or reduced costs for future launch vehicles due to the higher propellant efficiency as compared to all-rocket systems. In rocket-based combined cycles air-breathing engines such as ramjets and scramjets are integrated with rocket engines to enable use of atmospheric oxygen for a portion of the flight. The contractor shall conduct research and development on critical components of the rocket-based combined cycle engine such as: advanced inlets, diverters, mixers/combustors, nozzles, forebodies, and steady or unsteady pulsed rocket thrusters.

The scope of work under this element includes the following:

(1) The contractor shall develop and validate empirical, statistical, and physics-based analytical models for designing and/or predicting performance of RBCC components and entire propulsion systems.

(2) The contractor shall analyze and design advanced RBCC components and entire propulsion systems.

(3) The contractor shall conduct research and development of materials, structures, thermal protection, thermal management, and propellant management necessary to bring RBCC to fruition.

(4) The contractor shall fabricate test, and evaluate RBCC components and entire propulsion systems.

(5) The contractor shall develop and demonstrate advanced RBCC components and entire propulsion systems.

3.0 Work Requirements

The contractor(s) shall have the ability to perform all work in one or more of the Technology Areas as authorized in each task order issued.

The contractor(s) shall provide a program management system that includes timely insight into the technical, cost, and schedule status and risk, as well as technical and programmatic control of work performed under the task orders.

The contractor(s) shall implement a product assurance system, as appropriate, for task orders involving hardware and/or software development. The contractor's existing product assurance plans, procedures, formats, and documentation systems that support the development of safe and reliable aerospace products, are acceptable if they are shown to satisfy the objectives of the Product Assurance Requirements listed in the Product Assurance Requirements of NASA Policy Directive NPD 8730.5 NASA Quality Assurance Program Policy—URL: <http://nodis3.gsfc.nasa.gov/displayDir.cfm?t=NPD&c=8730&s=5>

All work performed under this contract shall be in compliance with all applicable Federal, state, and local environmental regulations and those policies set forth in the NASA Glenn Research Center's Environmental Programs Manual This can be viewed at: <http://smad-ext.grc.nasa.gov/shed/pub/epm/epm-manual.pdf>

Task Orders will be issued in accordance with Clause H.9-H.11.

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NASA has requirements for the development and demonstration of advanced engine technologies that will enable reductions in noise, emissions, fuel consumption, and sonic boom (high speed aircraft). Specific goals have been defined by NASA’s Subsonic Fixed Wing (SFW) and Supersonic Projects and are summarized in Tables 1 and 2, respectively.

TABLE 1.—GOALS FOR SUBSONIC FIXED WING PROJECT

Corners of the trade space	N+1 (2015) ^a Generation Conventional Configurations relative to 1998 Single Aisle	N+2 (2020) ^a Generation Unconventional Configurations relative to 1997 Large Twin Aisle	N+3 (2025) ^a Generation Advanced Aircraft Concepts (relative to user-defined reference)
Noise (cum. below Stage 4)	–32 dB	–42 dB	–71dB
LTO NOx emissions (below CAEP/6)	–60%	–75%	Better than –75%
Performance: aircraft fuel burn	–33% ^b	–40% ^b	Better than –70%
Performance: field length	–33%	–50%	Exploit metro-plex concepts ^c

^aTechnology Readiness Level Range = 4 to 6

^b An additional reduction of 10 percent may be possible through improved operational capability.

^c Concepts that enable optimal use of runways at multiple airports within the metropolitan areas.

TABLE 2.—GOALS FOR SUPERSONICS PROJECT

	N+1 Supersonic Business Class Aircraft (2015)	N+2 Small Supersonic Airline (2020)	N+3 Efficient Multi-Mach Aircraft (beyond 2030)
Environmental goals			
Sonic boom	65 to 70 PLdB	65 to 70 PLdB	65 to 70 PLdB low boom flight; 75 to 80 PldB overwater flight
Airport noise (cum. below stage 4)	Meet with margin	10 EPNdB	10 to 20 EPNdB
Cruise emissions	Equivalent to current subsonic	< 10	< 5 and particulate and water vapor mitigation
Performance goals			
Cruise speed, Mach	1.6 to 1.8	1.6 to 1.8	1.3 to 2.0
Range, nmi	4000	4000	4000 to 5500
Payload, passengers	6 to 20	35 to 70	100 to 200
Fuel efficiency, pass-miles per lb of fuel	1.0	3.0	3.5 Š 4.5

Flight regime related factors include

Subsonic: Focus is on Ultra-High Bypass (UHB) ratio engine technologies for the N+1 goals and embedded engine and variable engine technologies for the N+2 goals, and also includes development of lower Technology Readiness Level (TRL) advanced technologies enabling propulsion systems for the N+3 time frame.

Supersonic: Focus is on variable cycle engine technologies for the N+2 goals and may also include development of advanced technologies enabling propulsion systems for the N+3 time frame. Some work may also be included to address N+1 system as required.

Hypersonic: The Hypersonic Project is developing technologies to enable reusable air-breathing access to space and to enable high mass planetary entry for Mars and other planets. For reusable air-breathing access to space technologies, the Project is aligned with the goal defined in the 2007 National Plan for Aeronautics Research, namely, to demonstrate sustained, controlled, hypersonic flight. Successful sustained, controlled, hypersonic flight requires continued R&D into all areas of high speed atmospheric flight, including integrated aircraft design, aerodynamics, aerothermodynamics, high-temperature structures and materials, lightweight and durable thermal-protection systems, supersonic combustion, and propulsion concepts that operate from subsonic speeds into the hypersonic regime. The Hypersonic Project R&D goals include extending the temperature and life of high-temperature materials and structures, reducing component mass, developing air-breathing propulsion technology for Two-Stage-to-Orbit vehicles, and developing physics-based integrated multi-disciplinary design tools.